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Impact of Foliar Nutrient Application on Quality Attributes and Leaf Nutrient Composition in Kinnow Mandarin

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The quality of Kinnow mandarins (Citrus reticulate Blanco) is significantly influenced by the application of micronutrients, which play a crucial role in enhancing fruit attributes. This study evaluated the effect of foliar applications of 1.5% zinc sulfate, 0.6% boric acid and 0.5% potassium sulfate on various quality parameters of Kinnow mandarins cultivated in North India. Key quality metrics analyzed included juice content, peel content, rag content, peel thickness, total soluble solids (TSS), acidity, ascorbic acid and the TSS/acid ratio. Foliar nutrient treatments resulted in an increase in juice content and a reduction in peel and rag content, thereby improving the edible portion of the fruit. Peel thickness was minimized, contributing to better consumer acceptance. Additionally, significant improvements were observed in biochemical parameters: TSS, acidity, ascorbic acid levels and the TSS/acid ratio, enhancing the overall flavor and nutritional profile of the fruit. The study also examined leaf nutrient status (N, P, K, Zn and B), confirming improved uptake

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and utilization of essential nutrients under the foliar treatments. These findings underscore the importance of precise micronutrient management for achieving superior fruit quality in Kinnow mandarins.

Keywords: Kinnow; quality parameters; juice content; peel thickness; TSS; acidity; ascorbic acid; foliar nutrients.

1. INTRODUCTION

The Kinnow mandarin (*Citrus reticulata* Blanco) has become a key citrus fruit in North India, valued for its unique flavor, vibrant color, and economic significance. As a hybrid of the "King" and "Willow Leaf" mandarins, the Kinnow is celebrated for its deep yellowish- orange color, aromatic richness and refreshing taste, which makes it popular in both domestic and international markets (Kumar et al., 2022). Cultivated mainly in the subtropical regions of Punjab, Haryana, Rajasthan and Himachal Pradesh, its production has grown substantially due to its adaptability to various agro-climatic conditions and high yield potential (Singh et al., 2023).

Recent research underscores the increasing importance of the Kinnow mandarin as a major citrus crop, attributed to its excellent processing qualities and high juice content. The fruit's appeal is heightened by its balanced sweet-sour flavor, which aligns with the rising consumer demand for healthy and flavorful food options (Gurjer et al., 2018). Despite it’s advantages, Kinnow production faces challenges, particularly related to micronutrient deficiencies in zinc and boron, which significantly impact fruit quality and yield (Obeed et al., 2017). Effective management of these micronutrients is essential to address issues such as fruit drop, reduced yield and diminished quality (Davinder et al., 2017).

Recent studies have focused on the role of micronutrient application in boosting the growth, yield and quality of Kinnow mandarins. Research has demonstrated that foliar treatments with zinc sulfate, boric acid and potassium sulfate can significantly enhance fruit characteristics and overall productivity (Rana et al., 2023). For example, these treatments improve growth metrics like fruit weight, length and diameter, as well as quality attributes such as juice content and total soluble solids (TSS) (Razzaq et al., 2013; Babu et al., 2007). These findings highlight the importance of integrated nutrient management strategies to optimize Kinnow cultivation and maintain its economic benefits.

With global demand for citrus fruits on the rise, understanding and addressing the factors affecting Kinnow mandarin production is crucial for preserving its competitive edge and maximizing agricultural potential (Yadav et al., 2014). As of the latest data, Kinnow cultivation in India spans approximately 4,73,000 hectares, reflecting its growing prominence in Indian agriculture, particularly in northern states. Notably, Haryana contributes around 58,000 hectares to this total, emphasizing its significant role in Kinnow production within India.

Zinc plays a vital role in enhancing Kinnow mandarin growth parameters. Its application can lead to improved plant height, better leaf development, increased fruit set and quality, stronger root growth and enhanced disease resistance, ultimately boosting productivity and fruit quality (Chaudhary et al., 2016; Zaman et al., 2019). Boron also has a significant impact on Kinnow mandarin growth, particularly fruit length. Adequate boron application promotes cell elongation, reduces fruit drop and improves nutrient uptake that ultimately resulting in longer, more uniformly shaped fruits. When used in conjunction with other nutrients like zinc, potassium and boron further optimizes fruit development. Proper management of boron is essential for achieving longer fruits, better quality and higher yields.

Micronutrients play a crucial role in the quality of Kinnow mandarins (Citrus reticulata Blanco), influencing various attributes from fruit size to taste and nutritional content. Here’s how key micronutrients affect the quality of Kinnow mandarins:

Fruit Weight and Size: Zinc is essential for proper fruit development. Adequate zinc levels lead to increased fruit weight and size by promoting cell division and elongation (Chaudhary et al., 2016). Zinc enhances fruit color and reduces premature fruit drop, leading to a higher percentage of marketable fruits. It also contributes to better fruit shape and uniformity (Zaman et al., 2019). Zinc influences the accumulation of sugars and other essential compounds in the fruit, improving taste and overall flavor profile (Chaudhary et al., 2016). Fruit Length and Shape: Boron is vital for cell wall formation and elongation, which enhances fruit length and results in more uniformly shaped fruits. Adequate boron levels prevent fruit drop and improve fruit set (Obeed et al., 2017). Boron improves fruit firmness and reduces the incidence of disorders such as corky tissue. This leads to better texture and a longer shelf life (Davinder et al., 2017). Boron helps in the efficient uptake and utilization of other nutrients, which indirectly benefits fruit quality by ensuring balancednutrition (Razzaq et al., 2013).

Juice Content and Flavor: Potassium is crucial for the synthesis of sugars and acids in fruits, which enhances juice content and balances the sweet-sour flavor profile. This results in a more flavorful and juicier fruit (Babu et al., 2007). Potassium contributes to fruit firmness and reduces the likelihood of fruit cracking or splitting, thereby improving texture and appearance (Gurjer et al., 2018).

Micronutrient management is essential for optimizing Kinnow mandarin quality. Proper application of zinc, boron, potassium, magnesium, and manganese enhances fruit size, shape, color, flavor and shelf life. Effective micronutrient management ensures that Kinnow mandarins meet high-quality standards, leading to better market acceptance and economic benefits for producers (Yadav et al., 2014).

Fruit quality is a key factor influencing the export potential of citrus fruits (Deng, 1996). In Kinnow mandarins, the application of zinc sulfate ($ZnSO_4$) has been shown to enhance critical quality parameters such as total soluble solids (TSS), titratable acidity, sugars and vitamin C content. Zinc plays a vital role in enzymatic activities, auxin synthesis and antioxidant development, which contribute to improved fruit physiology and quality (Dutta and Banik, 2007; Nawaz et al., 2008). Studies have consistently reported that foliar $ZnSO_4$ applications enhance sugar synthesis, increase vitamin C accumulation and improve total antioxidant and phenolic content in citrus fruits (Dawood et al., 2001; Trivedi et al., 2012; Song et al., 2015). Zn treatment also enhanced the total sugar contents of 'Khasi' mandarin fruit (Babu and Yadav, 2005) These findings highlight the significance of zinc as a crucial micronutrient in improving the export quality of Kinnow mandarins.

2. MATERIALS AND METHODS

The current study, "Influence of foliar application of nutrients on fruit set, yield, and quality of Kinnow Mandarin," was carried out in 2023–2024 on ten -year-old kinnow Mandarin trees at Experimental Orchard and Post-harvest Technology Laboratory of Department of Horticulture at CCS Haryana Agricultural University, Hisar. These plants were set aside specifically to collect data on various physiological and biochemical parameters. The delineation of materials and methods practiced in the present study are as follows:

2.1 Experimental Site

Field trials were carried out in the Department of Horticulture, CCS Haryana Agricultural University, Hisar Experimental Orchard (29º 10' N latitudes and 75º 46' E longitudes), which is situated at 215.2 m above mean sea level.

2.2 Weather and Climate

Hisar has a typical semi-arid climate, with extremely cold winters and scorching, dry summers. It is typical for the area to see highs of about 45ºC in the summer, from May to June and lows of almost freezing in the winter, from December to January.The amount of precipitation overall and how it is distributed throughout the area are very variable. Approximately, 450 mm or 80 per cent of the annual precipitation, falls between July and September. Due to the western disturbances, a few showers also occur between December and February.There are notable fluctuations in the precipitation, ranging from 20–30 per cent annually to 30–50% seasonally.

2.3 Experimental Details

Three replications of each treatment, including fifteen combinations, were arranged in a randomized block design. Plants that were marked after 10 years of steady development and spaced six by six meters were selected for the current study. Throughout the trial, plants were maintained using standard orchard management procedures, with all procedures carried out in accordance with package instructions for the following treatments:

Treatments:

T_1	:	$ZnSO_4$ (1%)
T_2	:	$ZnSO_4$ (1.5%)
T_3	:	Boron(0.3%)
T_4	:	Boron (0.6%)
T_5	:	K_2SO_4 (0.25%)
T_6	:	K_2SO_4 (0.5%)
T_7	:	$ZnSO_4$ (1%) + Boron (0.3%) + K_2SO_4 (0.25%)
T_8	:	$ZnSO_4$ (1%) + Boron (0.6%) + K_2SO_4 (0.5%)
T_9	:	$ZnSO_4$ (1%) + Boron (0.3%) + K_2SO_4 (0.5%)
T_{10}	:	$ZnSO_4$ (1%) + Boron (0.6%) + K_2SO_4 (0.25%)
T_{11}	:	$ZnSO_4$ (1.5%) + Boron (0.3%) + K_2SO_4 (0.25%)
T_{12}	:	$ZnSO_4$ (1.5%) + Boron (0.3%) + K_2SO_4 (0.5%)
T_{13}	:	$ZnSO_4$ (1.5%) + Boron (0.6%) +K_2SO_4(0.25%)
T_{14}	:	$ZnSO_4$ (1.5%) + Boron (0.6%) + K_2SO_4 (0.5%)
T_{15}	:	Control (No application)

Treatments details

Crop	:	Kinnow Mandarin
Number of treatments	:	Fifteen (15)
Time of foliarapplication	:	First week of March Last week of April
Replications	:	Three per treatment (3)
Experimental Design	:	Randomized Block Design

Quality parameters

- Juice content (%)
- Peel content(%)
- Rag content (%)
- Peel thickness(mm)
- Total soluble solids(%)
- Acidity(%)
- Ascorbic acid (mg/100ml juice)
- TSS/Acid Ratio

Leaf Nutrient status: N,P,K,Zn,B

The content of N,P,K,Zn,B were estimated in the leaf of Kinnow Mandarin.

2.4 Methods

The materials and methods used for the current studies are bestowed below the subsequent heads:

2.5 Quality Parameters

2.5.1 Juice content (%)

The fruits were sliced into equal halves, and a basic juice extractor was used to extract the juice. Juice weight was measured using an electronic balance, and juice percentage was calculated by adding up the weight of the fruit and the juice.

$$\text{Juice content (\%)} = \frac{\text{Total juice weight}}{\text{Total weight of fruits}} \times 100$$

2.5.2 Peel content (%)

The five arbitrarily chosen fruits were peeled manually and the peel was weighed with electronic balance and percentage of peel was computed by using total weight of the fruit and weight of the peel.

$$\text{Peel content (\%)} = \frac{\text{Peel weight}}{\text{Fruit weight}} \times 100$$

2.5.3 Rag content (%)

The remaining residue after extraction of juice was considered as rag and the percentage rag content was evaluated by using the following formula:

$$\text{Rag content (\%)} = \frac{[\text{Fruit weight} - (\text{Peel weight} + \text{Juice weight})]}{\text{Fruit weight}} \times 100$$

2.5.4 Peel thickness (mm)

The five fruits that were selected at random were manually peeled. Using a digital vernier caliper near the fruit's equator, the peel thickness was assessed, and the average value was calculated and reported in millimeters (mm).

2.5.5 Total soluble solids (%)

Five randomly selected fruits' juices were separated in order to calculate the total soluble solids (%), which was then expressed as a percentage and evaluated using an automated hand refractometer.

2.5.6 Acidity (%)

The titratable acidity was estimated using the method suggested by AOAC (2000). Reagents prepared

The associated reagents were set up for further use:

1. Sodium hydroxide 0.1 N
2. Phenolphthalein indicator 1 %

Procedure

Two milliliters of newly separated juice was taken. It was titrated against N/10 sodium hydroxide administered in a burette after two drops of 1% phenolphthalein indicator were added. The end point was indicated by the appearance of a pale pink tint that persisted for a moment or longer. Citric acid percentage was used to convey acidity.

$$\text{Acidity (\%)} = \frac{\text{Titrate value} \times 0.0064}{\text{Juice taken (ml)}} \times 100$$

2.5.7 Ascorbic acid (mg/100 ml of juice)

The ascorbic acid content was detected by the standard method (AOAC, 2000).

Chemicals

1. 2,6-dichlorophenol indophenol dye ($C_{12}H_6Cl_2NaO_22H_2O$) - 50 mg
2. Sodium bicarbonate ($NaHCO_3$) - 42 mg

Procedure

Using 10 milliliters of distilled water, 50 milligrams of 2, 6-dichlorophenol indophenol dye and 42 milligrams of sodium bicarbonate were dissolved to create a final volume of 200 milliliters. The dye was filtered before being refrigerated in a dark-colored bottle.

Standard ascorbic acid solution (St.): 50 ml of 3 per cent metaphosphoric acid was used to dissolve 50 milligrams of ascorbic acid ($C_6H_8O_6$).

Estimation: 2 ml of juice and 3 percent metaphosphoric acid were used as a buffer. With 2,6-dichlorophenol indophenol dye, it was titrated until a pale pink hue emerged. The findings were expressed as milligrams of ascorbic acid for every 100 milliliters of juice.

$$\text{Ascorbic acid (mg/100 ml juice)} = \frac{\text{Titrate value} \times \text{Total volume}}{\text{St. reading} \times \text{juice taken (ml)}} \times 100$$

2.5.8 TSS to acid ratio

The TSS to acid ratio was calculated by dividing TSS with the acidity.

2.5.9 Plant leaf analysis

The content of Nitrogen, Phosphorous, potassium, zinc and boron were assessed in the leafduring the month of October.

Procedure

In October, healthy leaf samples from non-fruiting shoots that were five to six months old were obtained. They were then washed under running water, followed by 0.1 percent HCl, and twice through distilled water to ascertain the state of the leaf nutrients. After being cleaned, the samples were first surface dried and then oven dried for 48 hours at 70°C. Using Chapman's (1964) approach, the dried samples were crushed and sieved through muslin fabric for additional analysis.

2.6 Digestion of Plant Material

0.5g of ground-up leaf material was added to each of the 50 ml conical flasks, along with 10 ml of an acid combination (H_2SO_4: $HClO_4$ in a 9:1 ratio). Jackson (1973) used digestion on a heated plate to measure the amounts of nitrogen, phosphate, and potash. The aliquot was designed with a 50 ml total capacity.In order to illustrate micronutrients like Fe and Zn, Piper (1966) developed a procedure that involved putting 0.5 g of crushed leaf sample in 50 ml separate conical flasks, digesting them on a hot plate, and then adding 15 ml of a diacid mixture (HNO_3: $HClO_4$ in a 4:1 ratio). The aliquot was designed with a 50 ml total capacity. The content of nutrients was detected by using the following methods:

Nitrogen

The Nessler's reagent method, as detailed by Jackson (1973), was used to determine the nitrogen content.

Reagents

The solution of sodium silicate (10g) was prepared by dissolving it in 100 milliliters of purified water and filtering it.

i. NaOH (10%) solution: Ten grams of sodium hydroxide were dissolved in one hundred milliliters of distilled water and then filtered.
ii. Nessler's reagent: In 400 milliliters of water, 100 grams of potassium and 100 grams of mercuric iodide were dissolved, and in an additional 400 milliliters of water, 100 grams of NaOH was dissolved. After combining the two solutions, distilled water was added to bring the total volume to one liter.

Procedure

A 50 ml volumetric flask holding a 0.2 ml aliquot was filled with 1 ml sodium silicate and 0.5 ml 10% NaOH. Neck cleaning was followed by a thorough blending of the substances. After adding 2 ml of Nessler's reagent and shaking, the mixture was left for 30 minutes before being diluted to 50 ml. The optical density at 420 nm was measured using the Spectronic-20 spectrophotometer in comparison to a blank. Using a standard curve, the nitrogen concentration was determined and expressed as g/100 g on a dry weight basis.

Phosphorous

Jackson (1973) developed the Vando-molybdophosphoric acid yellow color method, which was used to determine the phosphorus content in leaves.

Reagents

i. Vanadate-molybdate reagent: solution "A" was created by dissolving 25 g of ammonium molybdate in approximately 400 ml of warm water. Similarly, 1.25 g of ammonium metavandate was dissolved in around 300 ml of warm water to create solution "B." This solution was cooled to room temperature before 250 ml of concentrated HNO_3 was added and cooled once more. After that, both solutions were thoroughly blended, and one liter of distilled water was used as the final amount.
ii. 6N HCL solution: 513 ml of concentrated HCL was taken, and distilled water was added to make the final amount one liter.
iii. Indicator of 2,4 Dinitrophenol (2.5%): 100 milliliters of 95% ethanol were used to dissolve the 2.5 grams of 2,4 dinitrophenol.
iv. Solution of ammonia

Procedure

A 50 ml volumetric flask was filled with five milliliters of aliquot, to which two to three drops of 2,4 dinitrophenol indicator were added. Next, ammonia solution was added until a yellow hue developed, and 6N HCl was added until the mixture was colorless. After adding 5 milliliters of vanda-molybedate solute, 25 milliliters of distilled water were used as the final volume. After completely blending the solution, the optical density was measured at 440 nm using a Spectronic-20 spectrophotometer against a blank. The standard curve was utilized to calculate the phosphorus concentration, which was then represented as g/100 g on a dry weight basis.

Potassium

The digested extract was measured using a flame photometer to estimate the potassium concentration, in accordance with the procedure outlined by Piper (1966). On a dry weight basis, the content was computed and expressed as a percentage.

Zinc

The specimens were collected using a leaf punch and these samples burnt directly. By using the dithizone, zinc content of the ash was estimated.

Boron

An acid extract of plant tissue ash is used to measure the amount of boron in it using a colorimetric approach that uses the azomethine H reagent. With a 3.2 per cent coefficient of variation, the procedure consistently produced a certified value of 33±3 ppm B for NBS orchard leaf reference material No. 1571

2.7 Statistical Analysis

A variance analysis was performed on the experimental data. In order to compare treatment means, the critical differences (C.D.) at the 5 per cent level of probability were computed. The Randomized Block Design (RBD) analysis protocol was followed in their analysis. The tables present an overview of the therapies' noteworthy outcomes.

C.D. = S.E. (d)× "t" at 5 % error degree of freedom

Where,

S.E. (d) =Standard error (SE) of difference of two treatment mean
t = t distribution tabulated value for error degree of freedom at 5% significance.

3. RESULTS AND DISCUSSION

3.1 Effect of Foliar Application of different Nutrients on Juice Content (%), Peel Content (%) and Rag Content (%) of Kinnow Mandarin

The data tabulated in Table 1 revealed that different nutrients significantly affected the quality parameters *i.e.*,juice content,peel content and rag content. The highest juice content (49.33%) was observed with T_{14} Zinc sulphate (1.5%)+Boric acid (0.6%)+Potassium sulphate (0.5%) which was statistically superior to all the treatments. Minimum juice content (44.67%) was recorded in T_{15}*i.e.*, control and was similar with T_2 (46.00%). Various chemical treatments significantly affected peel content of Kinnow mandarin fruits. Minimum peel content (24.33%) was observed with T_{13} Zinc sulphate (1.5%)+Boric acid (0.6%)+Potassium sulphate (0.25%).Maximum peel content (29.02%) was observed in T_{15} *i.e.*,control. Rag content was significantly affected by different nutrients treatments.

Maximum rag content (25.97%) was recorded with T_{15} control which was similar with T_{14} (25.51%). Lowest rag content (24.44%) was recorded in T_{11}*i.e.,* Zinc sulphate (1.5%)+Boric acid (0.3%)+Potassium sulphate (0.25). Rattanpal et al. (2005) observed that potassium treatments increased peel content, with the highest in Kinnow mandarins recorded at 5% KNO3 and 20 ppm 2,4-D. Vijay et al. (2016) found 4% KNO3 and 3% K2SO4 resulted in maximum peel content (27.81%) and peel thickness (4.94 mm) in sweet orange (var. Jaffa). Zinc foliar application boosts juice content in Kinnow mandarins by enhancing enzymatic activities, nutrient assimilation and sugar metabolism. The combined use of zinc, boron and potassium reduces rag content by improving cell wall integrity, tissue development and nutrient balance, leading to better fruit quality and a higher pulp-to-rag ratio.

3.2 Effect of Foliar Application of different Nutrients on Ascorbic Acid (mg/100ml Juice) of Kinnow Mandarin

The data given in Table 2 reveal that ascorbic acid of Kinnow mandarin was significantly affected by different nutrients. The maximum ascorbic acid content (31.58mg/100ml juice) was found in T_{14} Zinc sulphate (1.5%) + Boric acid (0.6%) + Potassium sulphate (0.5%) which was statistically at par with T_{13} (31.24 mg/100ml juice) and T_{12} (31.18mg/100ml fruit juice). The minimum value (29.40 mg/100ml juice) was seen in T_{15}*i.e.*, control.T_2 (30.10mg/100ml juice), T_4 (30.15 mg/100ml juice) and T_7 (30.17 mg/100ml juice) were found similar with T_{15} control. Pre-harvest Zn spray has also been shown to increase vitamin C content in citrus varieties (Dawood et al., 2001). Zinc's role in auxin synthesis and its enhancement of vitamin C accumulation in Kinnow mandarin have been documented (Nawaz et al., 2008).

3.3 Effect of Foliar Application of different Nutrients on TSS (Brix), Acidity (%) and TSS/Acid Ratio of Kinnow Mandarin

The data pertaining to TSS (^{0}Brix) is tabulated in Table 3 which was found significant towards the different nutrients applied.It is evident from Table 3 thatT_{14} Zinc sulphate (1.5%)+Boric acid (0.6%)+Potassium sulphate (0.5%) resulted in maximum TSS (9.83^{0}Brix) which was statistically at par with T_9(9.67^{0}Brix). The minimum TSS (8.70^{0}Brix) wasobserved in T_{15}*i.e.,* control which was similar to T_4 (8.90^{0}Brix). The result presented in Table 3 depicted that minimum acidity (0.83%) was observed in T_{14}- Zinc sulphate (1.5%)+Boric acid (0.6%)+Potassium sulphate (0.5%) which was statistically at par withT_9(0.84%). The maximum value(0.94%) was seen in T_{15} control and similar effect was seen in T_4 (0.92%) andT_7 (0.90%).The TSS/acid ratio was affected significantly and the maximum TSS/acid ratio (11.9) was observed in T_{14}*i.e.*, Zinc sulphate (1.5%)+Boric acid (0.6%)+ Potassium sulphate (0.5%) which was statistically at par with T_9 (11.5). The minimum TSS/acid ratio (9.3) was reported in T_{15}*i.e.*, control and was similar toT_4(9.7). Zinc's effect on aldolase enzyme activity, crucial for sugar synthesis, may explain increased sugar levels in fruits (Alloway, 2008). Zinc treatment has also been shown to increase total sugar content in Khasi mandarin fruits (Babu and Yadav, 2005) and enhance TAO and TPC levels in various fruits (Jan & handi et al., 2015). Foliar application of micronutrients like Cu, B and Zn improve fruit quality in terms of TSS content (Pamila et al., 1992; Ullah et al., 2012). Borax concentration has been found effective in enhancing TSS, total sugar, and reducing titratable acidity in aonla fruits (Shukla et al., 2011).

3.4 Effect of Foliar Application of different Nutrients on Peel Thickness (mm) of Kinnow Mandarin

The data given in Table 4 reveal that peel thickness of Kinnow mandarin was significantly affected by different nutrients. The maximum peel thickness (3.88mm) was found in T_{15} control which was similar with T_3 (3.77mm) and T_1 (3.74 mm). The minimum value (3.48 mm) was seen in T_{13}*i.e.*, Zinc sulphate (1.5%) + Boric acid (0.6%) +Potassium sulphate (0.25%) T_{14} (3.55mm), T_7 (3.55mm) and T_8 (3.58mm) were similar with T_{13}. The application of zinc, boron, and potassium significantly impacts the peel thickness of Kinnow mandarins. Zinc enhances enzymatic activity and cell division, promoting uniform peel thickness. Boron strengthens cell walls, improving structural integrity and preventing peel cracking. Potassium regulates water balance and nutrient translocation, which can increase peel thickness. Together, these nutrients ensure optimal peel thickness, improving fruit quality and resistance to damage.

3.5 Leaf Analysis

3.5.1 Nitrogen content

It is obvious from the data displayed in Table 5 that leaf nitrogen content was considerably influenced with various nutrients during investigation. The maximum N content (2.44%) was observed in T_{12}*i.e.*, Zinc sulphate (1.5%) + Boric acid (0.3%) + Potassium sulphate (0.5%) closely followed by T_8 (2.44%), T_{14} (2.37%), T_{11} (2.37%), T_5(2.36%) and T_{13} (2.33%).

Table 1. Effect of foliar application of different nutrients on juice content (%),peel content(%) and rag content(%) of Kinnow mandarin

Treatments	Juice Content (%)	Peel Content (%)	Rag Content (%)
T_1:$ZnSO_4$ (1%)	47.00	26.67	25.02
T_2: $ZnSO_4$ (1.5%)	46.00	26.33	25.06
T_3: Boron(0.3%)	48.33	26.00	25.13
T_4: Boron (0.6%)	47.33	25.67	25.23
T_5: K_2SO_4 (0.25%)	48.00	24.67	25.13
T_6: K_2SO_4 (0.5%)	47.67	27.33	24.91
T_7: $ZnSO_4$ (1%) + Boron (0.3%) + K_2SO_4(0.25%)	48.00	26.69	24.62
T_8: $ZnSO_4$ (1%) + Boron (0.6%) + K_2SO_4 (0.5%)	48.33	25.00	24.54
T_9: $ZnSO_4$ (1%) + Boron (0.3%) + K_2SO_4 (0.5%)	48.67	26.36	25.01
T_{10}: $ZnSO_4$ (1%) + Boron (0.6%) + K_2SO_4(0.25%)	47.67	25.68	24.45
T_{11}:$ZnSO_4$ (1.5%) + Boron (0.3%) + K_2SO_4(0.25%)	47.00	26.03	24.44
T_{12}: $ZnSO_4$ (1.5%) + Boron (0.3%) + K_2SO_4(0.5%)	46.67	24.68	25.34
T_{13}:$ZnSO_4$ (1.5%) + Boron (0.6%) + K_2SO_4(0.25%)	47.67	24.33	24.54
T_{14}: $ZnSO_4$ (1.5%) + Boron (0.6%) + K_2SO_4(0.5%)	49.33	25.67	25.51
T15: Control (no application)	44.67	29.02	25.97
C.D. at 5% level of significance	1.42	1.45	0.25

Table 2. Effect of foliar application of different nutrients on ascorbic acid(mg/100mljuice)of Kinnow mandarin

Treatments	Ascorbic acid (mg/100mljuice)
T_1:$ZnSO_4$ (1%)	31.06
T_2: $ZnSO_4$ (1.5%)	30.10
T_3: Boron(0.3%)	31.18
T_4: Boron (0.6%)	30.15
T_5: K_2SO_4 (0.25%)	30.43
T_6: K_2SO_4 (0.5%)	30.80
T_7: $ZnSO_4$ (1%) + Boron (0.3%) + K_2SO_4 (0.25%)	30.17
T_8: $ZnSO_4$ (1%) + Boron (0.6%) + K_2SO_4 (0.5%)	31.12
T_9: $ZnSO_4$ (1%) + Boron (0.3%) + K_2SO_4 (0.5%)	31.08
T_{10}: $ZnSO_4$ (1%) + Boron (0.6%) + K_2SO_4 (0.25%)	31.10
T_{11}: $ZnSO_4$ (1.5%) + Boron (0.3%) + K_2SO_4 (0.25%)	31.08
T_{12}: $ZnSO_4$ (1.5%) + Boron (0.3%) + K_2SO_4 (0.5%)	31.18
T_{13}: $ZnSO_4$ (1.5%) + Boron (0.6%) + K_2SO_4 (0.25%)	31.24
T_{14}: $ZnSO_4$ (1.5%) + Boron (0.6%) + K_2SO_4 (0.5%)	31.58
T15: Control (no application)	29.40
C.D. at 5% level of significance	0.45

Table 3. Effect of foliar application of different nutrients on TSS (^{0}Brix), acidity or TSS/acid ratio of Kinnow mandarin

Treatments	TSS (^{0}Brix)	Acidity (%)	TSS/Acid Ratio
T_1:$ZnSO_4$ (1%)	9.49	0.86	11.0
T_2: $ZnSO_4$ (1.5%)	9.20	0.89	10.4
T_3: Boron(0.3%)	9.07	0.89	10.2
T_4: Boron (0.6%)	8.90	0.92	9.7
T_5: K_2SO_4 (0.25%)	9.40	0.86	10.9
T_6: K_2SO_4 (0.5%)	9.50	0.86	11.1
T_7: $ZnSO_4$ (1%) + Boron (0.3%) + K_2SO_4 (0.25%)	9.10	0.90	10.1
T_8: $ZnSO_4$ (1%) + Boron (0.6%) + K_2SO_4 (0.5%)	9.27	0.87	10.6
T_9: $ZnSO_4$ (1%) + Boron (0.3%) + K_2SO_4 (0.5%)	9.67	0.84	11.5
T_{10}: $ZnSO_4$ (1%) + Boron (0.6%) + K_2SO_4 (0.25%)	9.30	0.88	10.5
T_{11}:$ZnSO_4$ (1.5%) + Boron (0.3%) + K_2SO_4(0.25%)	9.20	0.89	10.4
T_{12}: $ZnSO_4$ (1.5%) + Boron (0.3%) + K_2SO_4 (0.5%)	9.43	0.87	10.8
T_{13}:$ZnSO_4$ (1.5%) + Boron (0.6%) + K_2SO_4(0.25%)	9.53	0.86	11.0
T_{14}: $ZnSO_4$ (1.5%) + Boron (0.6%) + K_2SO_4 (0.5%)	9.83	0.83	11.9
T15: Control (no application)	8.70	0.94	9.3
C.D. at 5% level of significance	0.15	0.01	0.3

The minimum N content (2.27) was recorded in T_{15} control. Zinc plays a key role in the synthesis of proteins and enzymes that are involved in nitrogen metabolism. It helps in the efficient uptake and utilization of nitrogen, thereby increasing leaf nitrogen content.

3.5.2 Phosphorus content

The data regarding P content is displayed in the Table 5. There was no significant variation observed in P content due to foliar application of different nutrients. Boron aids in phosphorus movement and distribution within the plant, especially to leaves and fruits, while also supporting cell division and cell wall synthesis, indirectly enhancing phosphorus utilization.

3.5.3 Potassium content

A perusal of data given in Table 5 reveal that leaf potassium content was significantly affected by various nutrients applied in Kinnow mandarin.

The maximum K content (1.06%) was observed in T_{11} *i.e.*, Zinc sulphate (1.5%)+Boric acid (0.3%)+Potassium sulphate (0.25%).Potassium directly affects leaf potassium content by improving nutrient balance, regulating water movement, and activating essential enzymes. Adequate potassium levels help maintain optimal physiological functions, leading to increased potassium content in the leaves.

3.5.4 Zinc content

The data revealing the effect of different nutrients on Zn content is shown in Table 6. Significant effect was observed on leaf Zn content by application of different nutrients. The maximum Zn content (14.82ppm) was observed in T_{14} *i.e.*, Zinc sulphate (1.5%)+Boric acid (0.6%)+ Potassium sulphate (0.5%).

3.6 Boron Content and Leaf Chlorophyll Content

The data revealing the effect of foliar application of different nutrients on Zn and B content and leaf chlorophyll content are shown in Table 6. The leaf B content was significantly affected by the foliar application of different nutrients. The maximum B content(24.73ppm) was observed in T_{14} *i.e.*, Zinc sulphate (1.5%)+Boric acid (0.6%)+ Potassium sulphate (0.5%).The observations pertaining to leaf chlorophyll content in leaves are shown in Table 6. It was evident that the different nutrients affected significantly. The maximum leaf chlorophyll content was recorded in T_{14} *i.e.*, Zinc sulphate (1.5%) + Boric acid (0.6%) + Potassium sulphate (0.5%) and minimum was observed in T_{15} *i.e.*, control (1.24).

Table 4. Effect of foliar application of different nutrients on peel thickness (mm) of Kinnow mandarin

Treatments	Peel thickness (mm)
T_1:$ZnSO_4$ (1%)	3.74
T_2: $ZnSO_4$ (1.5%)	3.72
T_3: Boron(0.3%)	3.77
T_4: Boron (0.6%)	3.74
T_5: K_2SO_4 (0.25%)	3.71
T_6: K_2SO_4 (0.5%)	3.63
T_7: $ZnSO_4$ (1%) + Boron (0.3%) + K_2SO_4 (0.25%)	3.55
T_8: $ZnSO_4$ (1%) + Boron (0.6%) + K_2SO_4 (0.5%)	3.58
T_9: $ZnSO_4$ (1%) + Boron (0.3%) + K_2SO_4 (0.5%)	3.68
T_{10}: $ZnSO_4$ (1%) + Boron (0.6%) + K_2SO_4 (0.25%)	3.72
T_{11}: $ZnSO_4$ (1.5%) + Boron (0.3%) + K_2SO_4 (0.25%)	3.62
T_{12}: $ZnSO_4$ (1.5%) + Boron (0.3%) + K_2SO_4 (0.5%)	3.62
T_{13}: $ZnSO_4$ (1.5%) + Boron (0.6%) + K_2SO_4 (0.25%)	3.48
T_{14}: $ZnSO_4$ (1.5%) + Boron (0.6%) + K_2SO_4 (0.5%)	3.55
T15: Control (no application)	3.88
C.D. at 5% level of significance	0.03

Table 5. Effect of different of nutrients on Leaf nutrient content (%) of Kinnow mandarin

Treatments	N(%)	P(%)	K (%)
T_1:$ZnSO_4$ (1%)	2.27	0.14	0.98
T_2: $ZnSO_4$ (1.5%)	2.32	0.15	0.97
T_3: Boron(0.3%)	2.32	0.14	1.02
T_4: Boron (0.6%)	2.27	0.14	0.97
T_5: K_2SO_4 (0.25%)	2.36	0.15	0.98
T_6: K_2SO_4 (0.5%)	2.22	0.15	1.04
T_7: $ZnSO_4$ (1%) + Boron (0.3%) + K_2SO_4 (0.25%)	2.31	0.14	1.02
T_8: $ZnSO_4$ (1%) + Boron (0.6%) + K_2SO_4 (0.5%)	2.44	0.15	0.97
T_9: $ZnSO_4$ (1%) + Boron (0.3%) + K_2SO_4 (0.5%)	2.29	0.14	1.04
T_{10}: $ZnSO_4$ (1%) + Boron (0.6%) + K_2SO_4 (0.25%)	2.32	0.14	1.06
T_{11}:$ZnSO_4$ (1.5%) + Boron (0.3%) + K_2SO_4 (0.25%)	2.37	0.14	1.06

Treatments	N(%)	P(%)	K (%)
T_{12}: $ZnSO_4$ (1.5%) + Boron (0.3%) + K_2SO_4 (0.5%)	2.44	0.15	0.98
T_{13}:$ZnSO_4$ (1.5%) + Boron (0.6%) + K_2SO_4 (0.25%)	2.33	0.14	1.05
T_{14}: $ZnSO_4$ (1.5%) + Boron (0.6%) + K_2SO_4 (0.5%)	2.37	0.15	1.04
T15: Control (no application)	2.27	0.14	0.97
C.D. at 5% level of significance	0.03	NA	0.01

NA: Not applicable

Table 6. Effect of foliar application of different nutrients on leaf nutrient content (%) and leaf chlorophyll content (mg/g) of Kinnow Mandarin

Treatments	Zn(ppm)	B(ppm)	Leaf chlorophyll Content (mg/g)
T_1:$ZnSO_4$ (1%)	12.21	23.04	1.37
T_2: $ZnSO_4$ (1.5%)	12.38	23.09	1.41
T_3: Boron(0.3%)	12.79	23.13	1.46
T_4: Boron (0.6%)	12.29	23.21	1.73
T_5: K_2SO_4 (0.25%)	12.07	23.08	1.88
T_6: K_2SO_4 (0.5%)	12.28	23.48	1.67
T_7: $ZnSO_4$ (1%) + Boron (0.3%) + K_2SO_4 (0.25%)	14.11	24.10	1.68
T_8: $ZnSO_4$ (1%) + Boron (0.6%) + K_2SO_4 (0.5%)	14.48	24.13	1.87
T_9: $ZnSO_4$ (1%) + Boron (0.3%) + K_2SO_4 (0.5%)	14.55	24.61	1.99
T_{10}: $ZnSO_4$ (1%) + Boron (0.6%) + K_2SO_4 (0.25%)	13.48	24.56	1.76
T_{11}: $ZnSO_4$ (1.5%) + Boron (0.3%) + K_2SO_4 (0.25%)	13.38	23.51	1.94
T_{12}: $ZnSO_4$ (1.5%) + Boron (0.3%) + K_2SO_4 (0.5%)	14.52	24.61	2.16
T_{13}: $ZnSO_4$ (1.5%) + Boron (0.6%) + K_2SO_4 (0.25%)	14.70	24.38	2.05
T_{14}: $ZnSO_4$ (1.5%) + Boron (0.6%) + K_2SO_4 (0.5%)	14.82	24.73	2.19
T15: Control (no application)	11.69	23.01	1.24
C.D. at 5% level of significance	0.19	0.05	0.02

4. CONCLUSION

The study demonstrates that the foliar application of zinc sulphate, boric acid, and potassium sulphate significantly improves the quality and nutrient content of Kinnow mandarins. Treatment T14 (Zinc sulphate 1.5% + Boric acid 0.6% + Potassium sulphate 0.5%) emerged as the most effective, resulting in superior juice content (49.33%), higher ascorbic acid content (31.58 mg/100 ml juice), optimal TSS (9.83 °Brix), and the highest TSS/acid ratio (11.9). Furthermore, it reduced rag content and peel thickness while maintaining desirable peel content.

Nutrient treatments positively influenced leaf nitrogen, potassium, zinc, and boron content, with T14 showing maximum enhancement. These improvements can be attributed to the synergistic effects of zinc, boron, and potassium in enhancing enzymatic activity, nutrient assimilation, and cell wall integrity, leading to better fruit quality and nutrient uptake.

The findings align with previous studies highlighting the benefits of micronutrient application on citrus fruits. This research underscores the importance of balanced nutrient management in improving the economic and nutritional value of Kinnow mandarins. Implementing these nutrient strategies can contribute to sustainable horticultural practices, higher yields, and superior fruit quality in citrus cultivation.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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